Physical activity assessment: comparison between movement registration and doubly labeled water method.

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Abschätzung der körperlichen Aktivität: Vergleich zwischen der Bewegungsregistrierung und der Wasser-Doppelmarkierungs-methode

Summary The doubly labeled water method for the measurement of average daily metabolic rate (ADMR), combined with a measurement of resting metabolic rate, permits the calculation of energy expenditure for physical activity under normal daily living conditions. This procedure was used to evaluate the use of movement registration for physical activity assessment under daily living conditions.

Subjects were 16 men and 14 women with normal weight (body mass index (BMI) 24.6±2.4 kg/m^2). Their body movement was registered with a triaxial accelerometer over a 7-day interval, simultaneous with an ADMR measurement with a doubly labeled water method. Resting metabolic rate was measured overnight in a respiration chamber (sleeping metabolic rate (SMR)) at the start of the ADMR measurement. Subjects did wear the accelerometer during waking hours. Accelerometer output (AO, counts/min) was related to physical activity as quantified by adjustment of ADMR for SMR. Additional studies were performed in 11 subjects with anorexia nervosa (BMI 16.7±1.7 kg/m^2) and 8 subjects with morbid obesity (BMI 45.3±6.8 kg/m^2).

AO explained most of the variation in ADMR, after adjustment for SMR (R^2 = 0.64, SEE = 0.9 MJ/d). Average AO was 1108±293, 1144±318, and 946±391 for subjects with normal weight, anorexia nervosa, and morbid obesity, respectively, and was not significantly different between the three groups. However, in the anorectics AO was significantly related to body mass index (r=0.84, < p 0,01), subjects with a BMI17 kg/m2 were equally or more active compared with control subjects, while subjects with a BMI < 17 kg/m^2 were equally or less active compared with control subjects. In the morbid obese group, 5 of the 8 subjects had a low activity level (AO < 900 counts/day) and the other 3 had a high activity level (AO1150 counts/day).

The triaxial accelerometer is an objective method that can be used to quantify physical activity related energy expenditure and to distinguish differences in activity levels between individuals.

Zusammenfassung Die doppelt-markierte Wassermethode (DLWM) zur Bestimmung des mittleren täglichen Energieumsatzes (ADMR), kombiniert mit einer Messung des Ruheenergieumsatzes, erlaubt die Berechnung des Energieaufwands für die körperliche Aktivität unter den normalen täglichen Lebensbedingungen. Dieses Verfahren wurde angewandt, um die Anwendung der Bewegungsregistrierung zur Abschätzung der körperlichen Aktivität unter den täglichen Lebensbedingungen zu bewerten. Untersuchungspersonen waren 16 Männer und 14 Frauen mit normalem Gewicht (body mass index BMI 24,6±2,4 kg/m^2). Ihre Körperbewegung wurde mit einem triaxialen Akzelerometer über ein 7-Tages-Intervall registriert, simultan mit einer ADMR-Messung mittels DLWM. Der Ruheenergieumsatz wurde über Nacht in einer Respirationskammer (sleeping metabolic rate SMR) zu Beginn der ADMR-Messung bestimmt. Die Probanden trugen das Akzelorometer tagsüber. Die Quantifizierung der Beziehung zwischen Akzelerometer-Output (AO, Impulse/min) und körperlicher Aktivität wurde durch die An-

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passung der ADMR an die SMR vorgenommen. Zusätzliche Untersuchungen wurden an 11 Personen mit Anorexia nervosa (BMI 16,7±1,7 kg/m^2) und 8 Personen mit morbider Fettsucht (BMI 45,3±6,8 kg/m^2) durchgeführt. Der AO erklärte die meisten Variationen in der ADMR, nach Justierung auf SMR (R^2=0,64, SEE=0,9 MJ/d). Der mittlere AO war 1108±293, 1144±318 und 946±391 für Personen mit Normalgewicht, Anorexia nervosa und morbider Fettsucht. Dieser Wert war nicht signifikant unterschiedlich zwischen den 3 Gruppen. In der Anorexia-nervosa-Gruppe war der AO signifikant mit dem BMI korreliert (r=0,84, p 0,01). Personen mit BMI < 17 kg/m^2 waren gleich oder stärker aktiv als die Kontrollpersonen, während Personen mit BMI kg/m^2 gleich oder weniger aktiv als die Kontrollpersonen waren. In der Gruppe der morbiden Übergewichtigen hatten 5 von 8 Personen ein niedriges Aktivitätsniveau (AO < 900 Impulse/d), während die anderen 3 Personen ein hohes Aktivitätsniveau (AO > 1150 Impulse/d) aufwiesen. Das triaxiale Akzelerometer ist eine objektive Methode, um die körperliche Aktivität mit Bezug auf den Energieaufwand zu quantifizieren und Aktivitätsniveaus zwischen den Individuen zu unterscheiden.

Keywords Energy expenditure - accelerometer - doubly labeled water method - physical activity - human

Schlüsselwörter Energieumsatz - Akzelerometer - Wasser-Doppelmarkierungsmethode - körperliche Aktivität - Mensch

Introduction

The assessment of daily physical activity requires an objective method that can be used under normal daily living conditions, ideally over prolonged intervals of several days or weeks, and with minimal discomfort to subjects. Currently, the doubly labeled water method is generally accepted as the 'gold standard' for physical activity assessment in free-living subjects. This method determines the average daily metabolic rate (ADMR) and - combined with an estimate of resting metabolic rate - provides a reliable measure of energy expenditure associated with physical activity over periods of one to three weeks (8, 10, 11). The doubly labeled water method, however, can only be used to indicate the average level of daily physical activity and does not provide information about activity patterns in time. Furthermore, the high cost of the stable isotopes and the need for sophisticated analysis techniques limit its applicability to small populations. Nevertheless, the method is ideally suited as a reference technique for the evaluation of other methods for physical activity assessment.

Movement registration with body-fixed accelerometers seems to offer promising possibilities to reflect daily physical activity patterns in population studies. The present study was directed at evaluating a triaxial accelerometer for the assessment of daily physical activity in free-living subjects. A portable data unit was used for the on-line recording and storage of accelerometer output over 1 min intervals. Triaxial accelerometer and data unit together are referred to as the Tracmor. The accelerometer consisted of three uniaxial piezoresistive accelerometers, attached to the lower back of the subjects using an elastic belt around the waist, with measurement directions along the antero-posterior, medio-lateral, and longitudinal axis of the trunk.

During a one week period, physical activity was recorded with the Tracmor and compared with ADMR, determined with doubly labeled water and adjusted for sleeping metabolic rate (SMR) as determined in a respiration chamber. Subjects were in the normal body weight range. Subsequently, studies were performed in subjects with anorexia nervosa and in subjects with morbid obesity.

Methods

Subjects

Subjects were 16 men and 14 women (body mass index (BMI) 24.6±2.4 kg/m2), recruited from a six month follow-up study on the effect of diet composition on energy expenditure (3). Subjects had full time or part time employment with professions varying from office administrator to surgical nurse or dog-trimmer. Most subjects were engaged in leisure time sports activities. Additional studies were performed in 11 subjects with anorexia nervosa (BMI 16.7±1.7 kg/m2 (1)) and 8 subjects with morbid obesity (BMI 45.3 ± 6.8 kg/m2). The experimental protocol was approved by the ethics committee of the University of Limburg.

Protocol

Energy expenditure was measured over a two week interval under normal daily living conditions with doubly labeled water. Dose, sampling protocol, sample analysis, and calculation procedure were as described before (14). Subjects were given a weighed dose of water with a measured enrichment of about 5 atom % 2H and 10 atom % 18O so that baseline levels were increased with 150 ppm for 2H and 300 ppm for ^{18}O. Urine samples for isotope measurement were collected before dosing at night, from the second and last voiding on the next day, and after 7 and 14 days. Isotope abundances in the urine samples were measured with an isotope-ratio mass spectrometer (Aqua Sira; VG Isogas). CO2 production was calculated from isotope elimination rates, as calculated from the slope of the elimination curve, correcting for changes in body water assumed to be proportional to changes in body mass from the start to the end of the observation interval. CO2 production was converted to average daily metabolic rate (ADMR) using an energy equivalent based on the individual macronutrient composition of the diet (5).

Physical activity was quantificatied by adjustment of ADMR for resting metabolic rate as suggested by Carpenter et al. (4). The measure for resting metabolic rate was sleeping metabolic rate (SMR) observed at night during a 36h stay in a respiration chamber at the start of the ADMR measurement. SMR was measured over a 3-hour interval between 1.00 and 7.00 AM with the minimal activity level judged from Doppler radar observation. Subsequently, subjects did wore a triaxial accelerometer (2) over a 7-day interval, i.e., the first week of the two-week ADMR measurement. The accelerometer consisted of three uniaxial piezoresistive accelerometers, attached to the lower back of the subjects using an elastic belt around the waist with measurement directions along the antero-posterior, medio-lateral, and longitudinal axis of the trunk. A flexible cable ran from the accelerometer to a portable unit (110x70x35 mm, 250 gram) for on-line acquisition, processing, and storage of acceleration signals. The unit was programmed to calculate the sum of the rectified and integrated acceleration curves from all three measurement directions. The time period for integration was set at 1 min and the finally obtained output from the accelerometer and data unit (AO) was expressed as counts/min. Subjects wore the accelerometer during waking hours.

Results

In the normal weight subjects, mean ADMR was 12.4±2.0 (range 7.9-15.7) MJ/d, mean SMR was 7.0±1.0 (range 5.6-8.9) MJd, and mean Tracmor output, corrected for the influence of transportation (3), was 1108±293 (range 572-2017) counts/d. Plotting ADMR as a function of SMR (Fig. 1), the residual ranged from -2.3 to 4.8 MJ/d. The residual was closely correlated with Tracmor output (Fig. 2). In a linear regression analysis Tracmor output explained 64% of the variation in the ADMR adjusted for SMR with a standard error of estimate of 0.9 MJ/d.

With respect to the discrimination between separate levels of daily physical activity, Tracmor values were not significantly different from physical activity levels as quantified by the ratio between ADMR and SMR (PAL= ADMR/SMR), a measure favored by the World Health Organization (15). The PAL intervals recommended by this organization for activity levels with low, moderate, and high intensity correspond to Tracmor cut-off values of 900 and 1150 counts/min.

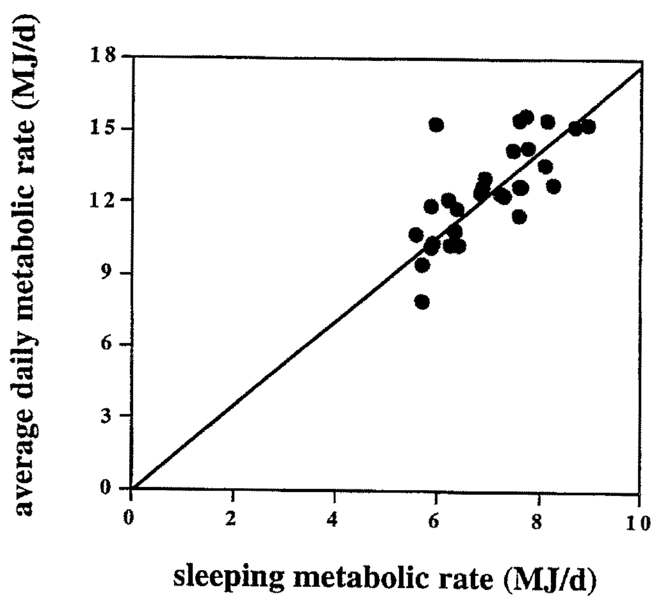

Fig. 1 Average daily metabolic rate plotted as a function of-sleeping metabolic rate with the calculated linear regression line in 16 men and 14 women with a normal body weight.

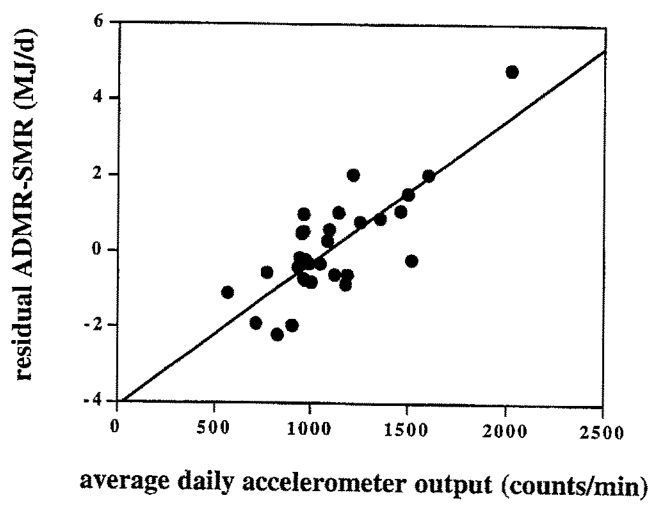

Fig. 2 The residual of the relationship between average daily metabolic rate and sleeping metabolic rate plotted as a function of average daily accelerometer output with the calculated linear regression line in 16 men and 14 women with a normal body weight.

Average AO, corrected for the influence of transportation (3), was 1144±318 and 946±391 for subjects with anorexia nervosa and morbid obesity, respectively, and was not significantly different from the value of 1108±293 in normal weight subjects (Fig. 3). However, in the anorectics AO was significantly related to body

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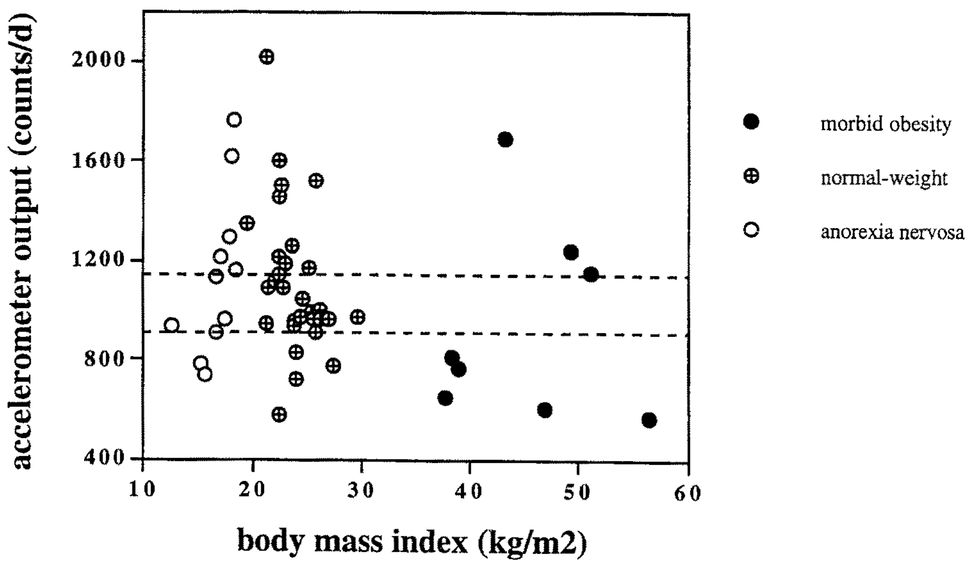

Fig. 3 Average daily accelerometer output plotted as a function of body mass index in 11 subjects with anorexia nervosa, 30 subjects with a normal body weight, and 8 subjects with morbid obesity.

mass index ($r=0.84$, $p < 0.01$), subjects with a BMI^{17} kg/m2 were equally or more active compared with control subjects, while subjects with a BMI < 17 kg/m2 were equally or less active compared with control subjects. In the morbid obese group, 5 of the 8 subjects had a low activity level (AO < 900 counts/day), and the other 3 had a high activity level (AO > 1150 counts/day).

Discussion

The present study was performed to evaluate the use of a Tracmor motion sensor for the assessment of daily physical activity in free-living subjects. This new method was compared with ADMR adjusted for SMR. Using average Tracmor output, corrected for the influence of transportation (3), 64% of the variation in adjusted ADMR under free-living conditions could be predicted. At least part of the unexplained variation can be ascribed to the performance of static exercise, or movement against external forces (like in pushing or pulling), which result in an increase of energy expenditure without a (proportional) increase in the amount of body movement. Furthermore, missing information about the hours the accelerometer and data unit were not worn, might have affected the prediction. By calculating average weekly Tracmor values it was assumed that these values represent body movement throughout the total 7-day observation period. However, the equipment is often not worn immediately after getting up in the morning until the very moment of going asleep at night, excluding some daily activities. Additionally, subjects told us that the Tracmor was sometimes not worn during intensive sports activities. Despite the shortcomings mentioned, a considerable part of the variation in daily energy expenditure could be predicted and it is expected that improvement of the wearing comfort of the Tracmor will improve the predictability.

When compared to other evaluations of accelerometers under free-living conditions, the field evaluation of the Tracmor showed good results. Correlations between Tracmor output and daily energy measures are generally stronger than those reported for other devices like Caltrac ($r = 0.49 - 0.54$ (6, 9)). A recently evaluated three-dimensional accelerometer (Tritrac) comparable to the Tracmor significantly underestimated free-living energy expenditure (7).

In the group with anorexia nervosa the results suggest that "paradoxical" overactivity only occurs in subjects with a BMI > 17 kg/m^2 (1). In the group with morbid obesity the level of physical activity was low in the majority of subjects, i.e., 5 out of 8, as has been shown before (12). The Tracmor appears to be a relatively cheap method to obtain information on the individual activity level.

In conclusion, the triaxial accelerometer is an objective method that can be used to quantify physical activity related energy expenditure and to distinguish differences in activity levels between individuals.

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